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Consequences of the IPPC-directive's BAT requirements for abatement costs and emissions

Abstract:
The *Integration Pollution and Prevention Control* (IPPC) directive from the European Union implies that the regulatory emission caps should be set in accordance with each industry's *Best Available Techniques* (BAT). The directive is under implementation in Norway, and it represents a refocus of the Norwegian environmental regulations away from economic efficiency towards a BAT principle. We examine the effect of this implementation with respect to expected emission reductions and increases in costs. *Data Envelopment Analyses* (DEA) is used to construct a frontier of all efficient plants. This provides us with two alternative interpretations of BAT. First, we assume that all the plants emit in accordance with the best practice technology, represented by the frontier, by reducing all inputs proportionally. Second, we assume that all plants emit in accordance with the best practice technology by reducing emissions only. Both interpretations reveal substantial potential for emission reductions. Further, abatement cost estimates indicate that considerable emission reductions can be achieved with low or no social costs, but that the implementation of BAT for all plants involves substantial costs.

Keywords: IPPC, BAT, Emissions, Energy intensive industries, DEA, Technical efficiency, Frontier technology.

JEL classification: D21, K23, K32, L61, L65, L73, Q48, R38.

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1. Introduction

The Integrated Pollution Prevention and Control directive (IPPC 1996) obliges the member states of the European Union to let each industry's *Best Available Techniques* (BAT) determine the conditions in the assignment of emission permits, i.e. reference values for emission limits will be based on BATs. Alternatively, instead of basing the emission limits on the best available techniques, the limits could be based on cost efficiency, such that further emission reductions occur for the plant whose marginal emission costs are the lowest. Until recently, the principle of economic efficiency was important in the Norwegian environmental regulations. Through the adoption of the IPPC directive into Norwegian law from 1999, the directive's BAT principle has received increased priority (Ministry of Environment 2002). It is well recognized by economists that for the same amount of pollution the overall social costs of a BAT principle are higher than the overall social costs evolving from adherence to the principle of cost efficiency. Hence, in the present paper we investigate the effects of the increased focus on the BAT principle in Norwegian environmental regulations: on emissions and abatement costs.

Before the implementation of the IPPC-directive in Norway, the anti-pollution law of 1981 emphasized overall economic efficiency. Indeed, in the most important documents for the interpretation of the law, a BAT principle was explicitly rejected in favor of a more cost efficient one (Bugge 1999, Ch. 8.2, Asdal 1998, Ot. Prp. 11 1979-80). Hence, the implementation of the IPPC-directive, required reformulations of the laws on provision of permits (Ministry of Environment 2002). Contrary to the pre-IPPC law, the new one explicitly relates the provision of permits to requirements concerning BAT.

In the first stage of the implementation, the directive applies to all new installations as well as existing ones that undergo significant changes. However, all establishments will require permits for to continue their activities from 2007.

The aim of our paper is to propose an illustration of the consequences for emission reductions and abatement costs of the implementation of the BAT requirements in Norway. We perform *Data Envelopment Analyses* (DEA) to construct frontiers for all technical efficient plants. The frontier consists of the firms within an industry using the *Best Practice Technique* (BPT). We estimate the changes in emissions due to the implementation of the BAT requirements in two alternative ways, both based on the difference between each plant's actual emission and the BPT emissions. First, we estimate *technical efficiency*, i.e. the ratio between the amount of inputs required to produce the observed output with the frontier technology, and the observed amount of inputs. This is a reasonable interpretation of the BAT given that the price ratio of traditional inputs and detrimental emissions reflects social costs of the society. However, if the price of detrimental emissions is undervalued, the intention of the directive should imply higher emission reductions. This price is not directly set in the market, but can be seen as a shadow price for the firms, reflecting the abatement costs. Then, and second, defining *environmental efficiency* as the movement to the frontier in the environmental dimension only, i.e. the ratio between the amount of detrimental emissions when producing the observed output with the frontier technology and the observed amount of detrimental emissions, holding traditional inputs constant, provides an alternative illustration.

Further, we illustrate the short-run costs for the plants and the society. We assume a so-called *putty-clay* technology, i.e. fixed short-run input coefficients, for which stricter permit standards are achieved solely through reductions in production. The social costs are calculated as the loss in aggregated value added minus wages.

We base the analysis on plant specific data from four of the most energy intensive industries in Norway; Pulp and paper, Primary aluminum, Ferro Alloy and Inorganic chemistry. These industries consume about 50 percent of energy in Norwegian manufacturing industries, thereby comprising the major contributors of total Norwegian emissions of pollutants to air in 2000. They caused more than 50 percent of emission of total acids, and about 50 percent of the emissions of CO_2 and other greenhouse gases. Thus, these industries face special attention from the Norwegian Pollution Control Authority (NPCA), and are subject to similar regulations, enforcement and deterrence policy.

Most papers that have studied the environmental implications of the IPPC-directive have used a life cycle assessment perspective (see e.g. Schultmann et al. 2001, Gelderman and Rentz 2001, Pellini and Morris 2001, Fatta et al. 2003). Lubbe-Wolff (2001) gives an overview of regulatory approaches in European countries, and relates these to the IPPC-approach. Except from these studies, we are not aware of any economics papers concerned with the IPPC from an empirical point of view. However, analyses of BAT-concepts, including e.g. *Best Available Technology Not Entailing Excessive Cost* (BATNEEC), are well known by economists; see e.g. Førsund (1992) and Pearce and Brisson (1993). Despite a growing literature on environmental efficiency (see e.g. Lansink and Silva, 2003, Reinhard et al. 2000, Bruvoll et al. 2003), our approach of using DEA in evaluating effects of the BAT requirement of the IPPC directive seems novel.

In the next section we define two interpretations of the BAT requirement: technical and environmental efficiency. These definitions are used to illustrate the emission reductions that can result from the implementation of the BAT requirement in Norway, see section 4. From economic theory, we expect that the refocus from cost efficiency to BAT requirements in Norwegian environmental regulations would be costly. In section 2 we also propose one way of estimating these costs, while the actual estimates are presented in section 5. Section 6 contains a concluding discussion.

2. Theoretical Framework

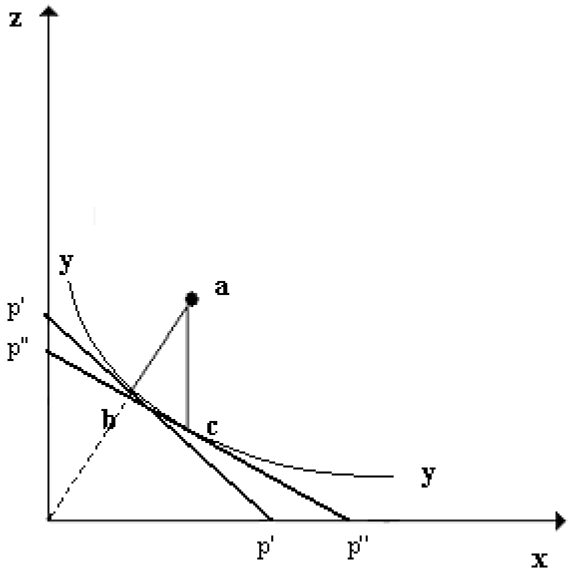
2.1. BPT as a representation of BAT

The Best Available Technique (BAT) may in principle include techniques not in use within the member states of the EU. However, in practice the BAT requirement does normally not include such techniques. The less demanding objective *Best Practice Technology* (BPT) mirrors the techniques already *actually employed* by existing plants in the industry. Therefore, the DEA method, composing the reference techniques using the *best practices* within each industry seems like a reasonable approximation to BAT.

We adopt BPT in two slightly different ways: the overall best practice techniques, and the best practice techniques in the environmental dimension only. The first approach represents a proportional reduction of all inputs including emissions. The second calculates the distance to the best practioners in the environmental dimension only. Arguments for each of these measures can be deduced from the reference to "*costs and advantages*" in Article 2 in the IPPC directive (IPPC 1996). Although this reference provides associations to the economics principle that marginal costs should equal marginal benefits, the principle itself is not vital in the determination of BAT (Faure and Lefevere 1999, Winter 1999, Lübbe-Wolff 2001).

As the environmental quality has no market price, the plant specific shadow price of pollution may fall short of the marginal costs to society. Then an over-proportionate reduction of the environmental detrimental emissions compared to normal inputs would be necessary to reach the economically efficient techniques. However, if the plant specific shadow price equals the marginal costs to society, the proportion between traditional inputs and detrimental emissions reflects the price ratio, and the economically efficient techniques could be reached by a proportional reduction of all inputs, including the environmentally detrimental one. We argue for that this method is a reasonable approximation to the economically efficient techniques.

Figure 1. Technical and Environmental Efficiency



This is illustrated in Figure 1 under the assumption of constant return to scale (CRS), where **x** denotes normal inputs and **z** environmentally detrimental inputs. The isoquant **y-y** is the technical efficient frontier that produces **y**. The plant **a** is technically inefficient. Assume that plant **a** faces the correct shadow prices of emissions. Then point **b**, where the isocost line **p'-p'** intersects with the frontier, is technically as well as economically efficient, i.e. a proportional reduction of the conventional and environmental inputs gives the technical as well as the economically efficient factor combination to produce **y**.

However, if plants do not pay the total marginal social costs, then the shadow price on the detrimental inputs for the plants is too low. In Figure 1, the isocost line reflecting a higher price on the environmental input is described as the line **p''-p''**. Then the economically efficient factor combination for the society is where the isocost line intersects with the frontier at **c**.

We now turn to describe how the BPT frontier is constructed, and to show how this reference technique can be compared to the actually employed techniques to determine the scope for emission reductions.

2.2. Technical and environmental efficiency

Assume we have observations of k (k = 1,…,K) plants using N ordinary inputs represented by a vector $x \in \Re^N_+$, and J environmentally detrimental inputs, $z \in \Re^J_+$, to produce M ordinary outputs, $y \in \Re^M_+$. The

$K \times N$ input matrix, X, $Z \times K$ undesirable inputs matrix, Z, and the $M \times$K output matrix, Y, represent the data for all K plants. Following Banker et al. (1984), these observations can be used to define a production set, S characterized by a convex hull.

(1) $$S=\{(y,x,z):x \text{ and } z \text{ can produce } y\}$$

Now we define the best practice technique frontier as the surface of S. For the case of a production technology using N normal and J environmental detrimental inputs to produce M outputs, following Shephard (1953, 1970) and Färe and Primont (1995), the input distance function can be defined as

(2) $$D(y,x,z) = \max_{\theta}\left\{\theta : \left(y, \frac{(x,z)}{\theta}\right) \in S, \theta \in R_+\right\}$$

In other words, the value of the input distance function measures the maximum amount by which the input vector can be deflated by a factor θ, given the output vector. It measures the minimal proportional contraction of the input vector required to bring it to the frontier of the input requirement set for a given output vector. A value greater than one for the input distance function implies that the observed input vector is inefficient. When the producer operates on the technical efficient frontier, then the distance function attains the value one, i.e. $\theta=1$.

Thus by definition, the reciprocal of the value of the input distance function provides an input-based Farrell measure of *technical efficiency* (Farrell 1957):

(3) $$TE(y,x,z) = \frac{1}{D(y,x,z)} .$$

If TE is 1 the plant is technical efficient. The measure (1-*TE*) is the proportion by which inputs could be reduced by improving technical efficiency, without reducing output.

Environmental efficiency can, accordingly, be defined in the environmental dimension, keeping outputs and normal inputs constant:

(4) $$D_E(y,x,z) = \max_{\phi}\left\{\phi : \left(y, x, \frac{z}{\phi}\right) \in S, \phi \in R_+\right\}$$

The *environmental efficiency* measure *EE* will then be defined as

$$EE(y,x,z)=\frac{1}{D_E(y,x,z)} \tag{5}$$

The distance function (D) for each plant can be computed by solving a linear programming problem. In our analysis we also assume constant returns to scale (CRS). To obtain the input saving efficiency measure (*TE*) for plant *k*, given output, the following linear programming problem must be solved for each unit. For unit *k* the optimization problem is:

$$\begin{aligned}
&TE_k = \min\theta \\
&s.t. \\
&-y_k + Y\lambda \geq 0 \\
&\theta\ x_k - X\lambda \geq 0 \\
&\theta\ z_k - Z\lambda \geq 0 \\
&\lambda \geq 0, \theta \leq 1 \\
&y_k \in Y,\ x_k \in X,\ z_k \in Z
\end{aligned} \tag{6}$$

λ is an $N\times 1$ vector of constants and θ is a scalar that measures the efficiency score for unit *k*. θ will satisfy $\theta \leq 1$, with the value 1 indicating a point on the frontier and hence a technical efficient plant according to the Farrell (1957) definition. This linear programming problem has to be solved for all *K* units. The intuitive interpretation of the DEA problem is that we take the k^{th} unit and seek to radial contract the input vector, (x_k, z_k), as much as possible, while still remaining within the feasible input set. The radial contraction of the input vector, (x_k, z_k), produces a projection point, $(\lambda x_k, \lambda z_k, y_k)$, on the frontier. The efficiency is the distance between this projection point and the observed data for unit *m*, (x_k, z_k, y_k).

To obtain the input saving environmental efficiency measure (*EE*) for plant *k* under constant returns to scale, given output and the conventional inputs, the following linear programming problem must be solved for each unit. For unit *k* the optimization problem is:

$$
(7) \quad
\begin{aligned}
& EE_k = \min \phi \\
& s.t. \\
& -y_k + Y\lambda \geq 0 \\
& x_k - X\lambda \geq 0 \\
& \theta\, z_k - Z\lambda \geq 0 \\
& \lambda \geq 0, \theta \leq 1 \\
& y_k \in Y,\, x_k \in X,\, z_k \in Z
\end{aligned}
$$

ϕ will satisfy $\phi \leq 1$, with the value 1 indicating a point on the frontier and hence an environmentally technical efficient plant. The intuitive interpretation of the DEA problem is that the k^{th} unit is used to contract the detrimental input vector, z_k, as much as possible, while still remaining within the feasible input set. This vector contraction of the emission vector, z_k, produces a projection point, $(\lambda z_k, x_k, y_k)$, on the frontier. The environmental efficiency is the distance between this projection point and the observed data for unit *k*, (x_k, z_k, y_k). From the definitions of TE and EE it follows that TE is always weakly higher than EE.

In our application we include capital, labor and material as conventional inputs, and emissions of greenhouse gases and acids as environmental inputs. The efficiency measures are calculated with both pollutants jointly.

2.3. The cost of reducing emissions

To illustrate the costs for the plants to fulfill the conditions determined by BAT, we use a modification of the method introduced by Pasurka (2001). We assume a *putty-clay* technology with constant returns to scale, where the input coefficients are fixed in the short run. When no investments are done, production must be reduced to achieve the required emission level. Since we study the process oriented capital-intensive manufacturing industry, we find it reasonable to employ this *putty-clay* assumption. We also assume that the permits given by the environmental authorities are on the total emission level for each pollutant, and the firms have to fulfill all emission levels in the permits.

The assumption that production reductions are the only way to reduce emissions in short run may not be realistic for pollutants that can easily be abated with end-of-pipe investments, like SO_2. However, the inefficient firms are obliged not only to reduce emissions of pollutants that can be abated through end-of-pipe investments, as acids, but also emissions of pollutants that are very costly or impossible to abate, like carbon dioxide. For the latter kind of pollutants, production reductions seem the only practicable way to reduce emissions in the short run.

Given the above assumptions, the costs for the plants to achieve emission level in accordance with the frontier technology can be calculated as the loss in the plants' net surplus exclusive capital costs, i.e. income from production minus short run costs. We assume a fully flexible labor market and disregard transitional unemployment costs.

3. Data

We base our study on an extensive database (DEED)[1], which consists of disaggregated environmental and economic data covering the largest and potentially most polluting Norwegian plants. On the international level, similar data is scarce.[2]

The data set consists of an unbalanced panel for each of these industries: Pulp and Paper, Aluminum, Ferro alloys and Inorganic chemicals.[3] Table 1 presents the size of our samples compared to the total industry. The plants in our samples cover a substantial proportion of the production and inputs of the actual industry. Mostly, this holds for emissions too. The missing observations are due to lacking or uncertain emission data. The data set contains about 40 different plants in all four industries each year. In this paper, we use data for the period 1996 to 2000 to construct the frontier, while we use the latest available year for which we have data (2000) to measure the distance to the frontier.

Plant specific output, intermediate inputs and capital are measured in current values, and deflated to 2000 NOK by industry specific output and input price indexes and price indexes for investments, respectively. Capital is estimated using a combination of insurance values of buildings and machinery and accumulation of net investments. Labor is the number of working hours in the plant. In addition, the emissions of two different pollutants are included. *Greenhouse gases* are an aggregate of carbon dioxide (CO_2), methane (CH_4) and nitrous oxygen (N_2O), measured in 1000 tonnes CO_2-equivalents. *Acidifying substances* are an aggregate of sulfur oxide (SO_2), nitrogen oxides (NO_x) and ammonium (NH_3), measured in tonnes weighed by the acidifying component (H^+). We perform the DEA analysis using OnFront 2.2 (Färe and Grosskopf, 2000).

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[1] DEED - Database for Disaggregated Environmental and Economic data, see Larsson and Telle (2003) for further documentation.

[2] For information on time series data in EU, see Berkhout et al. (2001). EPA provides data for the US (Toxic release inventory).

[3] NACE codes 21.1, 27.421, 27.35, and 24.13, respectively.

Table 1: The coverage of our sampled plants compared to the respective industries in year 2000

Industry	Pulp and paper			Aluminum			Ferro alloy			Inorganic chemicals		
	Industry	Sample	Coverage	Industry	Sample	Coverage	Industry	Sample	Coverage	Industry	Sample	Coverage
Plants	39	17	0,44	12	7	0,58	19	11	0,58	29	10	0,34
Production (million Euro[4])	1965	1357	0.69	2474	2445	0.99	6 057	5 947	0.98	747	733	0.60
Labor (1000 working hours)	9 641	7052	0.73	8 311	7 923	0.95	3 576	3 507	0.98	3 607	2 624	0.72
Energy (million Euro)	177	133	0.75	262	261	1.00	106	106	1.00	91	68	0.74

Source: Statistics Norway (2003)

4. Potential emissions reductions

4.1. Technical efficiency

Table 2 shows the calculated technical efficiencies as defined in Equation (3). The efficiencies vary across industries, and on average the technical efficiency is 88 percent. In the Aluminum industry, almost all plants operate on the frontier with an average efficiency of 99 percent, while the other three industries have an overall efficiency potential of between about 10 and 20 percent. In Table 3, these efficiency measures are transformed into emission reduction potentials. If all plants operated on the technical efficient frontier, greenhouse gases and acids would be reduced by 11 and 16 percent, respectively. The highest reduction potentials exist for acids in the Ferro alloy industry.

4.2. Environmental efficiency

The environmental efficiency measure calculates the distance to the frontier in the environmental dimension as defined in Equation (5). The environmentally detrimental inputs include both greenhouse gases and acidifying substances. Table 2 reveals substantial environmental inefficiencies. On average for all industries the efficiency score is 60 percent. This shows a large scope for emission reductions. Table 3 summarizes the potential emission reductions if all plants operated on the frontier. If all plants reduced their emissions corresponding to best practice environmental techniques, emissions of greenhouse gases and acids would on average fall by 36 and 54 percent, respectively. Again, the potential for emission reductions is smallest in the Aluminum industry. For the other industries the potential is vast, with reductions up to 83 percent for acid equivalents in the Ferro Alloy industry.

To sum up, our analysis shows that there is substantial potential for emission reductions by instructing all plants to implement the emission level in accordance with its industry's best-applied technology.

Hence, our results may be taken to indicate that we can expect reductions in emissions as the BAT requirement of the IPPC directive is implemented in Norway. However, such application of the IPPC directive might turn out to be very costly. In the next section we present estimates of such costs.

Table 2: Average technical and environmental efficiencies. Percent

	All industries	Paper and Pulp	Inorganic Chemistry	Ferro Alloy	Primary Aluminums
Technical efficiency	88	88	90	81	99
Environmental efficiency	60	58	62	41	92

Table 3: Average emission reductions if all plants were technically or environmentally efficient. Figures are weighted with emissions. Percent

		All industries	Paper and Pulp	Inorganic Chemistry	Ferro Alloy	Primary Aluminum
Technical efficiency	Greenhouse gases	11	12	12	20	2
	Acids	16	6	11	25	1
Environmental efficiency	Greenhouse gases	36	37	42	64	10
	Acids	54	20	39	83	5

5. The costs of emission reductions

The results presented in Table 4 show significant variation in costs across industries. When the emission standard is set according to the *technical efficient emissions*, the average unit costs for the plants of reducing greenhouse gases differ from 8 Euro/tonne for Ferro alloy to 90 Euro/tonne for Aluminum. For acids, the difference is significantly larger. For Aluminum, almost all plants are technically efficient and there is little potential for emission reductions for any of the pollutant, and therefore abatement of these emissions would be relatively costly.

When the emission standard is set according to the *environmental efficient emissions*, the average unit costs for the plants of reducing emissions are higher for both greenhouse gases and acids. Still, there is

[4] Average exchange rate 2000: 1 euro=8.11 NOK (Bank of Norway, 2004)

great variation in the average costs across industries. Again, emission reductions appear especially costly in the Aluminum industry.

Table 4: Average abatement costs per unit pollutant. Profit weighted with emissions. In Euro

		All industries	Pulp and paper	Inorganic chemistry	Ferro alloy	Primary Aluminum
Technical efficiency	Greenhouse gases Euro/tonne	17	70	12	8	90
	Acids Euro/kg	99	660	58	45	5740
Environmental efficiency	Greenhouse gases Euro/tonne	23	121	14	9	90
	Acids Euro/kg	140	1192	66	49	5823

Abatement costs differ not only between industries, but also between plants. In Figures 2 to 5, we have constructed the marginal abatement cost curve for the society by arranging our calculated costs per unit emission for each plant in ascending order. In the same graphs we have also plotted the accumulated costs for the society. We represent the costs as the reduction of short-run net surplus.

First, for the *technical efficiency measure*, the potential reduction if all plants adhere to emission caps that correspond to the emissions of the efficient plants, are about 718 thousand tonnes greenhouse gases or about 11 percent of the total emission of greenhouse gases from these industry branches. The abatement costs varies from negative values (i.e. benefit for both the firm and society) to 1 200 Euro/tonne emitted greenhouse gases. For acids, the reduction potential is 16 percent of the total emission and the average cost of such a reduction is almost 100 Euro/kg.

In the short run some plants make losses. However, if these losses are permanent, the plants will eventually have to close down. However, the losses could also be temporary, due to for example market failures. In our analysis, we have only analyzed one year and cannot investigate the reason for the losses in these plants. If all the plants with losses in the Pulp and paper and Inorganic chemical industry close down, there would be a 4 percent reduction of the total emissions of greenhouse gases from these industries. This is equals the emission reduction that would occur if all plants were emitting the same amount as the technically efficient plants. Such a closure of unprofitable plants would also give a surplus for the society besides the environmental gains. When we sum up the costs for the society in an accumulated social costs curve, we find that up to 54 percent of the potential reduction in emissions of greenhouse gases, or 6 percent of the total emissions of green house gases, could be achieved at zero social costs. However, to reduce emissions the last 20 percent necessary to reach the level of the frontier is very costly. For greenhouse gases, the cost to abate the last percentage of the potential is about 1 200 Euro/tonne.

The abatement cost profiles for acids is similar to the one for greenhouse gases; with a wide range between the plants with the lowest and the highest abatement costs. A reduction of 9 percent of the total emission could be achieved if the plants with economical losses were closed down. 70 percent of the potential reduction in emissions of acids, or 11 percent of the total emission of acids from these industry branches, could be abated without incurring social costs. However, the cost of abating the last percentage of the reduction potential compared to the frontier, is almost 16 000 Euro/kg.

Second, for the *environment efficiency measure*, the potential reduction if all plants adhere to emission caps that correspond to the emissions of the efficient plants is about 2.4 million tonnes for greenhouse gases, or about 36 percent of the total emission of greenhouse gases. Again, the calculations show that about 45 percent of the potential, or 16 percent of the total emissions, could be abated without any costs for the society. For acids, application of the environmental efficiency measure shows that the emissions of acids could be reduced by 44 percent. Nearly half of this reduction could be achieved without incurring social costs.

Figure 2. Social abatement costs for Greenhouse gases accumulated and per tonne emission, measured with technical efficiency

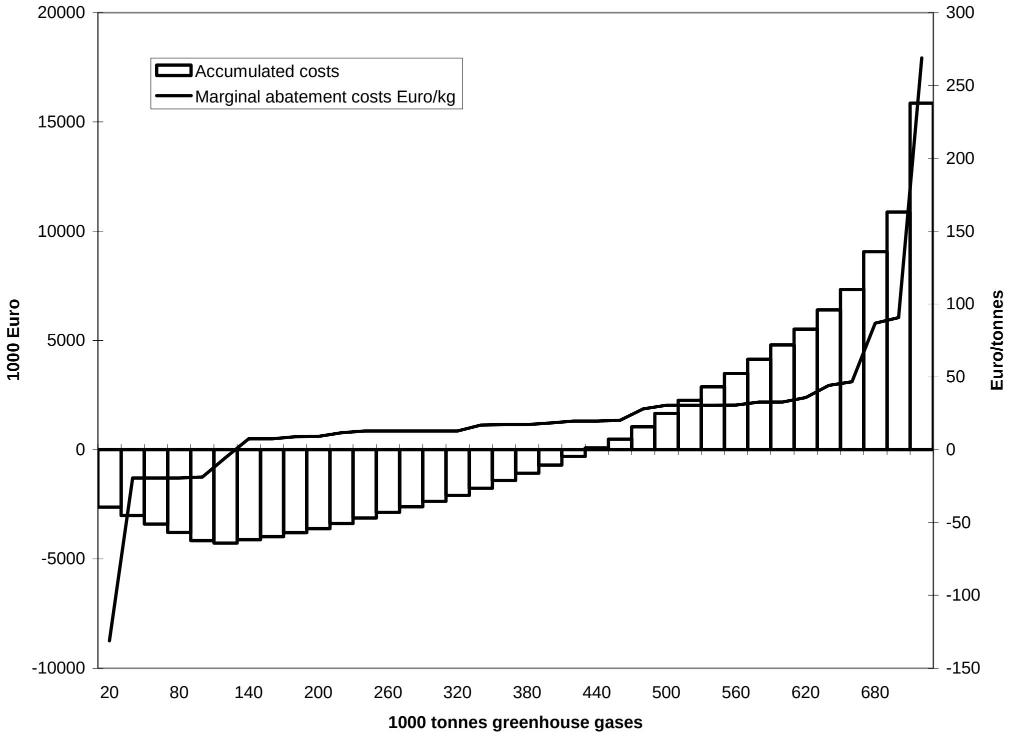


Figure 3. Social abatement costs for Greenhouse gases accumulated and per tonne emission, measured with environmental efficiency

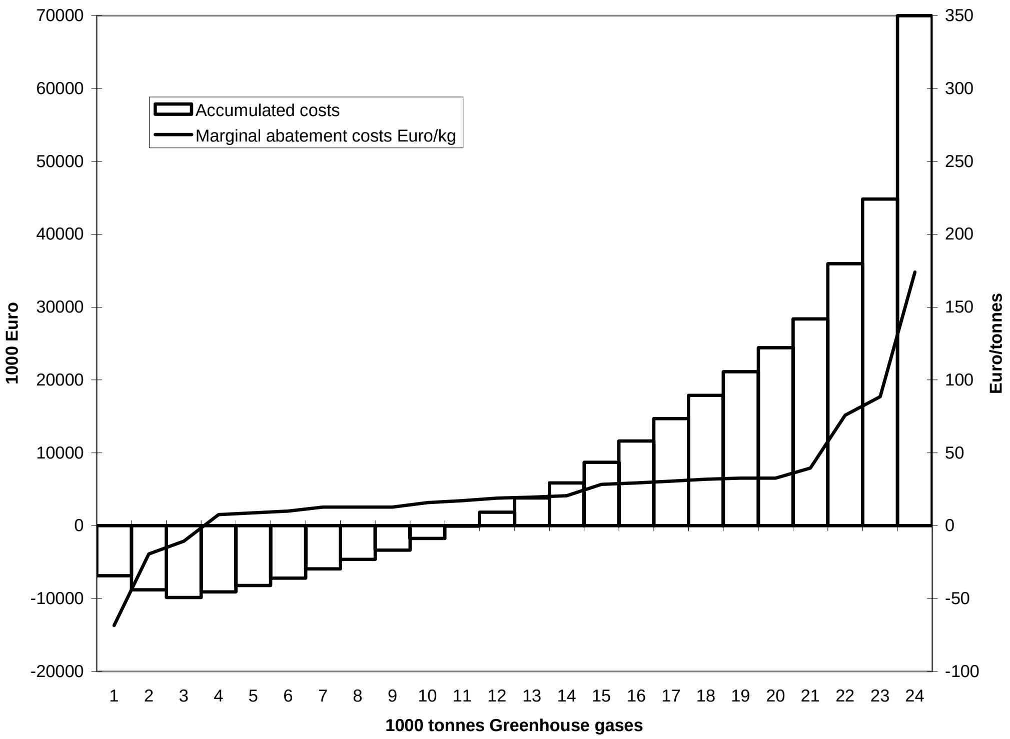


Figure 4. Social abatement costs for Acid equivalents accumulated and per tonne emission, measured with technical efficiency

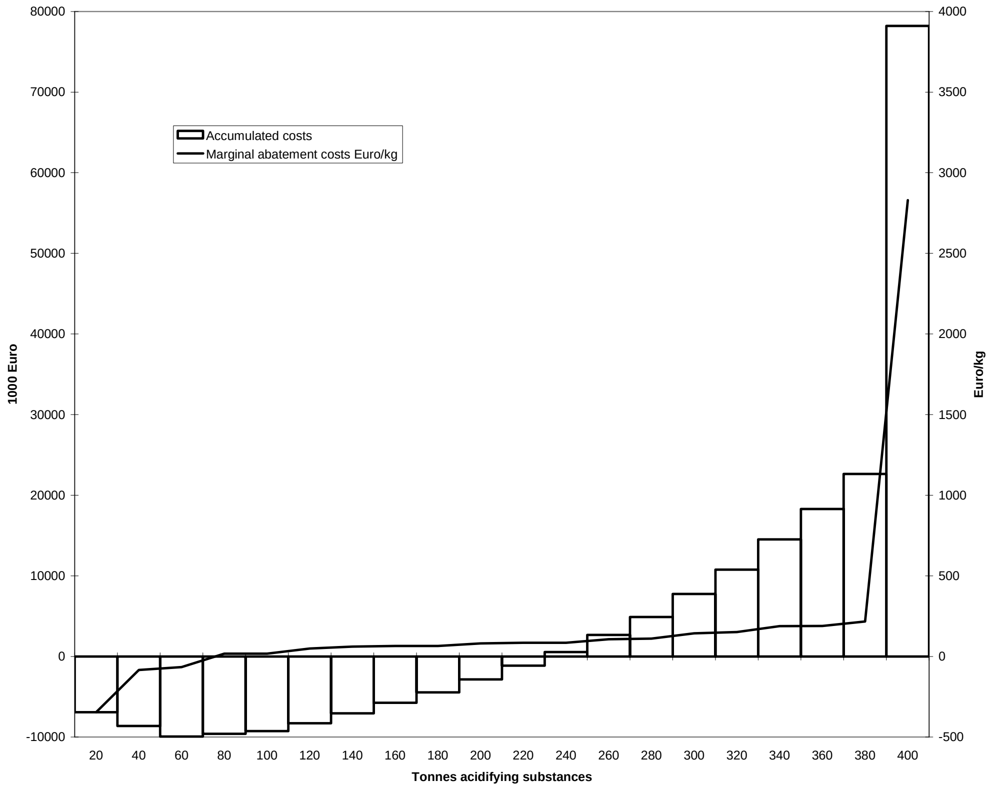
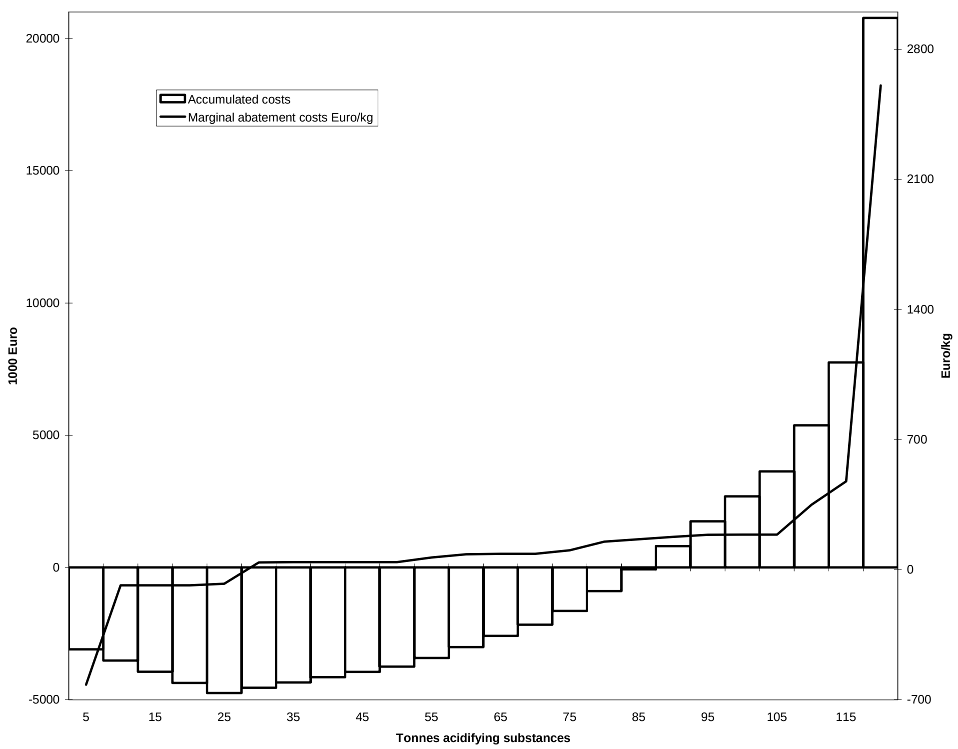


Figure 5. Social abatement costs for Acid equivalents accumulated and per tonne emission, measured with environmental efficiency



To sum up, the costs of achieving emission standards according to the BAT requirements differ significantly across industries and plants. Large emission reductions can be achieved without incurring social costs. However, the costs of having all plants emit in accordance with its industries best practice seem to be very high, at least for the last abated units. Our analysis may be taken to indicate that the costs associated with a shift from a system with focus on cost efficiency to one based on the BAT principle are substantial.

6. Concluding discussion

The IPPC-directive states that new establishments need permits to operate. The directive requires the allowed emission permits to be in accordance with each industry's *Best Available Technique* (BAT), and thus achieve the highest practicable level protection for the environment. This directive also states that existing establishments must operate in accordance with the requirements not later than 2007. Since 1999, the directive has been under implementation in Norwegian environmental regulations and policies (Ot. Prp. 59 1998-99, Ministry of Environment 2002).

In this paper we have investigated how the implementation of the IPPC directive for the most energy intensive industries in Norway may influence emissions and costs in these industries. We have applied two different interpretations of BAT. We defined BAT with respect to all factor input dimensions and with respect to environmental technologies only.

The results show that if all plants implement its industry's best practiced technology, overall emissions of greenhouse gases and acids will decline. The most conservative estimate indicates an average reduction of about 11-16 percent compared to the emission level in 2000. However, emissions of acids could be cut by about 54 percent if environmental techniques already in practice within each plant's sub-industry were implemented in all plants. The Aluminum industry seems most efficient, with hardly no scope for emission reductions, while the potential for emission reductions appears to be most profound in the Ferro alloy industry.

Also, the costs of reducing emissions are highly heterogeneous in our material: Some plants face very low abatement costs to reduce emissions, or emission reductions may even be profitable. These plants have net short-run losses. On the other hand, for plants on the other end of the abatement curve, it may be very costly to reduce emissions. Hence, requiring implementation of BAT for all plants at a given point in time may inflict considerable costs.

We have considered *technical* and *environmental* efficiency, with only limited concern for economic efficiency. In many cases technical efficiency is a prerequisite for economic efficiency, but in the presence of considerable investments costs, technical inefficiency may be consistent with economic efficiency in the short run.

In theory any level of emissions should be achieved so that marginal costs from emission abatement are identical across all plants. Under a BAT principle, such as the one focused at by IPPC where plants meet the same regulations regardless of costs, a given level of emissions will normally be achieved at higher costs. This argument was one of the main reasons why a strict BAT principle was rejected when the Norwegian anti-pollution law was launched in 1981 (Bugge, 1999). Although some corrections to avoid economic inefficiency are taken, our results indicate that the implementation of the BAT principle of the IPPC directive will reduce emissions but at the risk of not taking sufficiently account of economic efficiency. This implies that emission reduction could be achieved at lower costs, or alternatively that emissions could be further reduced at the same costs.

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